Fast build up of photorefractive spatial solitons in iron doped indium phosphide

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Photorefractive spatial solitons have attracted research in the past ten years not only for the attractive physics they involve but also because of potential applications among which can be found the optical communication domain. They are a special kind of spatial solitons which do not rely on a direct third order optical non-linearity but rather on an indirect one involving the electro-optic effect, charge motion and trapping and eventually index modulation via the linear electro-optics.

These phenomena are now well understood and a time-resolved model is able to describe their build-up. Their interactions have been deeply studied and arrays of them are now used to photo-induce photonic lattices. However, one is forced to note that the vast majority of the work undertaken in this field has yielded photorefractive spatial solitons which exist only in the visible range and that exhibit build-up times on the order of seconds, which is prohibitive for telecommunication or even sensor applications. And indeed, the materials which are mostly used for such experiments are insulators which present defects —intentional or not—, that allow them to be photorefractive. They exhibit, however, a somehow low free carriers mobility.

We have therefore focused our attention on the semi-conductor indium phosphide which can be made photorefractive —thus with a low conductivity— by iron doping. Aside from being well known and an industry standard, InP:Fe presents the double advantage of being sensitive in the infrared for the photo-electric effect and of its high free carriers mobility with respect to insulators. Its drawback is, however, its low electro-optic coefficient which makes it, at first glance, less attractive for photorefractive uses.

In spite of that, we have conducted experiments in the light of early works by M.Chauvet [1] and R.Uzdin [2]. Indeed, semi-conductors such as InP:Fe exhibit a two carrier type photorefractivity: in the case on indium phosphide, holes are mainly photo-generated, while electrons are thermally generated. Two Wave Mixing (TWM) based experiments and theoretical considerations have shown the leading role played by the intensity at which the generation rate of electrons and holes are equal, called the *resonance intensity*: around it, the photorefractive gain is maximum.

When the optical excitation is close to a spatial sine, the index modulation can be viewed in terms of real and imaginary part: the photorefractive gain is in this case proportional to the imaginary part which is itself maximum at resonance. It can be shown that the real part vanishes at resonance and changes sign around it. We have thus undertaken experiments to measure the resonance intensity by a two wave mixing approach in a variety of crystal samples we had[3] and at two wavelengths: 1.06 microns for the high sensitivity of InP:Fe and 1.55 microns for its telecommunications interests, and studied in particular its variations with the sample temperature.

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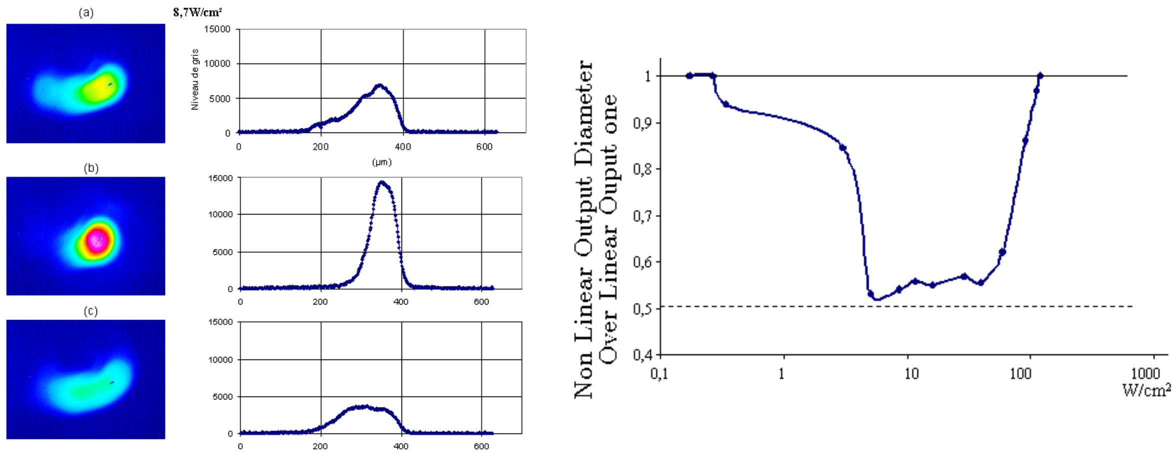

FIG. 1: *Left:* Linear output beam profile (a) 10kV/cm applied field (b) reverse applied field (c). The input beam waist is 25 microns. The 1.55 microns beam peak intensity is $9\mathrm{W/cm}^2$. *Right:* Output beam width function of maximum beam intensity, the dotted line reffering to the spatial soliton.

As hinted in [1], a link can be established qualitatively between (TWM) considerations and spatial solitons: indeed, the propagation of spatial solitons needs a *local-like* nonlinearity in which the refractive index variation is linked to the *local* value of the optical intensity; this in-phase component is what we called above *the real part*. Therefore, we could here conclude that the change of sign of the real part implies a change of sign of the local non-linearity: a transition from self-focusing and spatial solitons towards self-defocusing — or *vice-versa*. This is precisely the behavior which we tempted to reproduce in the samples we had. We never succeeded at reproducing this behavior: no change of sign of the local non linearity was ever observed, except by inverting the applied field. Rather, we have observed steady state self-focusing leading to a spatial soliton. We have thus measured the output diameter of the beam with respect to the input one and evidenced a behavior strangely similar to that we have observed and explained in insulators: strong effect around a given optimum intensity and disappearance for both low and high intensity (figure 1).

To explain these results, we tried to find a new quantitative model. We have succeeded in identifying both experimentally and theoretically the two-carrier *dark irradiance*, the one carrier counterpart of that which plays a key role in insulators. We have shown that the optimum intensity was thrice the dark irradiance, as in insulators, and evidenced a link between resonance intensity and dark irradiance which may explain the reasons why the resonance intensity can, or cannot, play a role in the experiments.

This theoretical analysis helped us in interpreting our results in terms of build-up times: we have thus shown that PR solitons build-up times in our InP:Fe samples was well below 1ms and probably around the microsecond for intensities typically found in optical networking. These results will be shown along with a theoretical analysis intended to serve as a base towards the thorough time resolved understanding of two carriers photorefractive solitons.

[1] M. Chauvet, S. A. Hawkins, G. J. Salamo, M. Segev, D. F. Bliss, and G. Bryant, Opt. Lett. **21**, 1333 (1996).
[2] R. Uzdin, M. Segev, and G. J. Salamo, Opt. Lett. **26**, 1547 (2001).
[3] We thank here the company InPact (Moutiers, France) and G.Salamo (University of Arkansas) for their high quality samples.